November 20, 1884.

MR. J. EVANS, Vice-President and Treasurer, in the Chair.

In pursuance of the Statutes, notice of the ensuing Anniversary Meeting was given from the Chair.

Professor Walter Noel Hartley and Professor Wilfrid H. Hudleston were admitted into the Society.

Mr. J. Ball, General Boileau, Sir James Cockle, Dr. Rae, and Mr. G. J. Symons, having been nominated by the Chairman, were by ballot elected Auditors of the Treasurer's Accounts on the part of the Society.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read :—

I. "Observations on the Harmonics of a String struck at one-eighth of its Length." By ALFRED JAMES HIPKINS (of John Broadwood and Sons). Communicated by ALEXANDER J. ELLIS, F.R.S. Received October 1, 1884.

The string observed was a steel pianoforte wire, gauge number $19\frac{1}{2}$, diameter 1·17 mm. = ·07 inch, of exactly 45 inches vibrating length, stretched by a tension of 71 kilogrammes = 156·63 lbs., and forming the note C of 135·2 vibrations, in the second space of the bass staff, in one of Broadwood's concert grand pianofortes accurately adjusted to be struck by the hammer at one-eighth the length of the string from the wrestplank end, or 39·375 inches from the belly-bridge. Actually three such strings, forming the usual trichord of a grand pianoforte accurately tuned in unison, were used to augment the volume of tone. The positions of all the nodes less than 39·4 inches from the belly-bridge for the first 20 harmonics, were previously calculated. All three strings were stopped at the same distance from the belly-bridge with the edge of a piece of felt glued to a piece of wood by Mr. Hartan, the foreman of the tuners, while I struck the note. A considerable weight and steadiness of blow was necessary to excite the harmonic. The sound at first was dull

and unmusical, but immediately afterwards the harmonic corresponding to the node touched, sang out, always clearly enough to be unmistakably recognised, and sometimes, especially where the node corresponded to several harmonics, with a long clear ring, that was made brighter and longer by removing the stopper from the string, which then vibrated in the small loops conditioned by the node touched.

The following are the first 20 harmonics of this C determined theoretically. Against each is placed its number of vibrations, and the name of the nearest note on the equally tempered scale, which was that of the piano used, with the theoretical number of hundredths of an equal semitone which had to be added to, or subtracted from, the pianoforte note, in order to give the true pitch of the harmonic. This list enabled the note heard to be immediately identified, by touching the corresponding notes on the pianoforte. Finally in the last column is given the number of inches from the belly-bridge at which one or more of the nodes of the harmonic would lie theoretically, for all the harmonics actually observed and brought out on the 29th July, 1884, in the presence of Dr. William Huggins, F.R.S., who verified the position of the node by a scale after the harmonic had been produced, and Mr. Alexander J. Ellis, F.R.S., who recorded the results. The examination of the numerous other positions of the nodes of these and other harmonics was omitted for brevity, as those possessing most interest had been already produced, but those obtained on other occasions are inserted in a parenthesis. Except in a few instances considered below, the practical place of the node did not differ from the theoretical by more than ·02 or ·03 inch, within which limits it was difficult to be sure of the measurement.

In calculating out the positions of all the nodes it was found that some lay very close together. Thus a node of the 17th harmonic lay at 5·29 inches from the bridge, between one of the 9th harmonic at 5 inches, and another of the 8th at 5·62, so that these nodes were only ·3 inch apart. All these harmonics were brought out separately, but great care was necessary to hit the precise spot. On the other hand the node of the 2nd harmonic at 22·5 inches lay between one of the 19th at 21·32 inches, or 1·2 inches nearer the bridge, and another also of the 19th at 23·68, or 1·2 farther from the bridge. Hence there was a space of 2·36 inches with only one harmonic node within it. Probably in consequence of this the 2nd harmonic could be brought out by touching the string at a considerable distance on either side of the theoretical place, because apparently the string had no other shape which it could assume. It was determined that the limits within which the 2nd harmonic could be brought out were from 22·1 to 22·95 inches from the bridge, allowing ·85 inch play, but at 22·05 and 23·0 inches from the bridge the harmonic would not speak.

Table of Harmonics.

No. of Harmonic.	No. of vibrations in a second.	Name of the nearest equally tempered note.	Distances in inches of the node from the further (belly) bridge at which the harmonic was brought out.
1	135·2	c	
2	270·4	c'	22·5.
3	405·6	$g'+2$	15·0 (30·0).
4	540·8	c''	(11·25, 33·75).
5	676·0	$e''-14$	9·0 (18·0, 27·0, 36·0).
6	811·2	$g''+2$	(7·5, 37·5.)
7	946·4	$b''\flat-31$	6·43 (12·86, 19·29, 38·57).
8	1081·6	c'''	5·63, 16·88, 28·13.
9	1216·8	$d'''+4$	5·0 (10·0, 20·0).
10	1352·0	$e'''-14$	4·5 (13·5).
11	1487·2	$f'''+51$	4·09 (20·45, 24·54, 28·63, 36·82).
12	1622·4	$g'''+2$	3·75.
13	1757·6	$a'''-59$	3·46.
14	1892·8	$b'''\flat-31$	(3·21, 35·36).
15	2028·0	$b'''-12$	3·0 (24·0, 33·0).
16	2163·2	c''''	2·81, 8·44.
17	2298·4	$d''''\flat+5$	5·29.
18	2433·6	$d''''+4$	12·5 (2·5.)
19	2568·8	$e''''\flat-2$	4·74.
20	2704·0	$e''''-14$	

Similarly for the 3rd harmonic which had its theoretical node at 15 inches from the bridge, between a node of the 19th at 14·21 inches and one of the 20th at 15·75 inches, leaving 1·64 inches unoccupied by nodes. Practically the 3rd harmonic spoke from 14·75 to 15·4 inches from the bridge, giving a "play" of ·65 inch, but would not come out at 14·7 or 15·45. These were the only two cases in which the amount of "play" was accurately determined. In each case the harmonic came out brightest and best at the theoretical node. Dr. Huggins said that he had remarked a similar phenomenon on the violin, where he found a "play" of about a quarter of an inch in "stopping" for the octave harmonic. Subsequently I brought out the 23rd harmonic $f''''\sharp$ + 28, vib. 3124·6, at 1·96 inches from the bridge. And going nearer, at 1·50 inches from, and until quite up to, the belly-bridge, I got out the dull prime note of the string C, without apparently any partial. The same note was produced also at 1·50 inches from the wrestplank-bridge. So that there is still more play for the prime note itself. The stopping seemed to obliterate all the upper partials, but allowed the string to vibrate as a simple tone in its full length. It is remarkable how many harmonics could be elicited by the means adopted from one length of string, and how

clearly the high harmonics even to the 19th came out. Also it was noticeable that the harmonic could be brought out by touching at any one of its nodes, even at those very far distant from the striking-point, showing how accurately a comparatively stout string of great tension could resolve itself into minute sub-vibrations. Thus the 19th harmonic was quite distinctly brought out, so as to be easily compared with $e''''\flat$, by touching the string at its second node from the bridge, leaving 40·26 inches of string to be agitated by the blow.

The object of the experiment was to determine, if possible, the effect of the striking place on the harmonics quenched. Helmholtz ("Tonempfindungen," fourth edition, p. 133) says that the striking place is from $\frac{1}{7}$ to $\frac{1}{9}$ the length, between which, of course, lies $\frac{1}{8}$, and observes (*ibid.*) that "an essential advantage of this striking place appears to be that the seventh and ninth partial tones disappear, or, at least, become very weak." I do not know of any pianos with the striking place at $\frac{1}{7}$ the length. Harpsichords and spinets, which were set in vibration by quill or leather plectra, had no fixed point for plucking the strings. It was generally from $\frac{1}{2}$ to $\frac{1}{10}$ of the vibrating length. Although it had been observed by Huyghens and the Antwerp harpsichord maker, Jan Couchet, that altering the plucking place altered the quality of tone, giving rise to the "lute stop" of the eighteenth century, no attempt was made to fix a uniform plucking place. On the latest improved spinet, a Hitchcock, of the early part of the eighteenth century, in my possession, the striking distances for the C's vary from $\frac{1}{2}$ to $\frac{1}{7}$. And on the latest improved harpsichord, a Kirkman, of 1773, also in my possession, the striking distances of the C's vary from $\frac{1}{2}$ to $\frac{1}{10}$, and the lute stop from $\frac{1}{9}$ to $\frac{1}{29}$ of the string. The bass or longest strings giving, of course, the shortest striking measures, and the same was true of the early pianofortes, as those of Stein, Mozart's favourite pianoforte maker. The great length of the bass strings as carried out on the single belly-bridge, copied from the harpsichord, made it impossible to equalise the striking place for that part of the scale. It was John Broadwood, in 1788, who first endeavoured to equalise the scale in tension and striking place. Assisted by Signor Cavallo and the then Dr. Gray of the British Museum, he produced the divided belly-bridge which enabled him to reduce the length of the bass strings, and hence gained a uniform striking place. He adopted $\frac{1}{9}$ the vibrating length, allowing much latitude in the treble. C. Kützing ("Das Wissenschaftliche der Fortepiano-Baukunst," Bern, Chur, und Leipzig, 1844, pp. 41–2) says the maximum should be $\frac{1}{8}$, and the minimum $\frac{1}{9}$ the length, but that the latter requires a softer hammer to bring out a pleasant tone, and that $\frac{1}{8}$ is much better. The present head of the house of Broadwood (Mr. Henry Fowler Broadwood) has arrived at the same conclusions, and adopted $\frac{1}{8}$ the vibrating length as the striking place for

his pianofortes. Kützing says that when he was an assistant he had to "equalise" instruments where the striking place was between $\frac{1}{12}$ and $\frac{1}{7}$ the vibrating length, and it is the latter place which Helmholtz has adopted for his table of experiments (*ibid.*, p. 135), in which the 6th harmonic is made very weak, and the 7th disappears altogether.

Now the table I have given shows that though the striking place was adjusted with great accuracy to $\frac{1}{8}$ the vibrating length, not only the 7th and 9th harmonics, but also the 8th and even the 16th, were brought out distinctly. The 7th was particularly strong and clear, and the 9th was very good indeed. The 8th harmonic was not so strong, but it was perfectly clear, and it was got out at three of its nodes. Of course, it has 7 nodes, but of the 4 where it was not brought out, 2 were nodes of the 4th harmonic, and 1 a node of the 2nd harmonic, and the 8th was, of course, absorbed in these, while the remaining node was the striking place itself. Perhaps the reason why the 8th harmonic did not disappear was that the striking surface of the hammer was not a perfectly hard edge, but a yielding surface, so that the blow spread on both sides of the intentional striking place, and thus excited the string at very slight distances from the node itself. But whatever may have been the cause the result was quite distinct, and recognised clearly by Dr. Huggins and Mr. Ellis, as well as myself and Mr. Hartan. So that there is no doubt whatever that striking with a pianoforte hammer at a node does not obliterate the corresponding harmonic.

For the 16th harmonic there are 15 nodes, 1 at the striking place, 1 between the striking place and the wrestplank-bridge, neither of which could be tried, 3 which were also nodes of the 8th harmonic, 2 of the 4th, and 1 of the 2nd. The remaining 7 belong to the 16th harmonic alone, and of these it was thought sufficient to try two, which produced the sound quite clearly. The neighbouring 15th and 17th harmonics also came out well. These are an additional proof that a pianoforte hammer striking at a node does not destroy the harmonic due to that node. Subsequently I had an opportunity of trying the middle c' string of one of Steinway's grand pianofortes. This string was 28·75 inches long, and was struck at 3·2 inches from the wrestplank-bridge, that is, at $\frac{1}{9}$ of its length. I got out the 6th, 7th, 8th, and 9th harmonics just as in Broadwood's piano, the 6th and 7th both beautifully strong; the 8th and 9th weaker, but clear and unmistakable—a further confirmation of the fact that the pianoforte hammer does not obliterate the harmonic at whose node it strikes.